Advances in Research at the National Renewable Energy Laboratory

Research Brief

Microalgae Serve Energy Needs

NREL Cultivating Biodiesel Source that Reduces Greenhouse Gases

Take some microscopic plants; put them in water that is unfit for other uses; expose them to the sun; feed them exhaust gas that threatens the Earth's climate. Then, when you get a bumper crop: harvest it; soak it first in solvent and then in alcohol mixed with catalyst; finally, feed it to your truck's fuel tank.

The National Renewable Energy Laboratory (NREL) has great hopes for this recipe as a means to promote American energy independence, reduce pollution and greenhouse gas emissions, and create a major new industry for the American Southwest and other areas—biodiesel from microalgae.

> Biodiesel: ester fuel derived from the oils and fats of renewable biological sources
>
> Ester: compound consisting of fatty acid and alcohol molecules

Biodiesel made from microalgae could promote American energy independence, reduce pollution and greenhouse gas emissions, and create a major new industry for the American Southwest.

Microalgal Fuel—A Good Substitute for Diesel

Many species of algae produce substantial quantities of lipids (fats and oils). Those lipids can be extracted and converted to fuels. The fuel most likely to prove commercially viable is biodiesel. Biodiesel requires little or no engine modification and provides power similar to conventional diesel fuel. Moreover, it produces lower particulate emissions and no sulfur emissions.

Biodiesel is already being produced on a limited basis from terrestrial oilseed crops such as soybean and rapeseed. But microalgae from saline ponds and other sources can produce 15 times as much oil per acre as oilseed crops. Carbon dioxide (CO_2), the highest cost item for producing microalgal fuels, may become available at low cost as a result of industry efforts to reduce emissions of greenhouse gas. Sunshine is readily available. Water and some vacant land—other resource needs—should also be low in cost.

NREL Working to Make Microalgae Even Better Lipid Producers

Technology for converting plant lipids to biodiesel is already well developed. American and European companies are already marketing biodiesel made from seed oils, using

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NREL researcher tends microalgal cultures used for mass culture research.

the same conversion technology that would be used for microalgae. First, solvent is used to extract the oils from the microalgae or seeds. An acid or an alkali catalyst is then used to combine the oils with an alcohol—a process known as transesterification. The resulting biologically based ester, while chemically different, has properties very similar to those of petroleum diesel and could also be used to produce substitutes for fuel oil and other petroleum distillates.

Work supported by the U.S. Department of Energy (DOE) has shown that microalgae can be grown successfully in outdoor ponds on a large scale. Research at NREL is currently focused on increasing the growth and production of lipids in selected microalgae strains.

Culture Collection Being Further Improved by Genetic Engineering

The road toward optimal microalgal lipid production started with researchers collecting more than 3000 strains of microalgae, mostly from desert and saline environments. Researchers then selected a number of strains that were promising because of high growth rates (nearly three doublings per day), high lipid production capacities, and tolerance for wide ranges of salinity and temperature. More than 400 of the original 3000 strains are maintained at NREL for further study.

In their natural state, promising microalgae contain from 5% to 20% lipids (ash-free dry weight). By manipulating growth conditions, researchers can increase the lipid content to more than 60% in laboratory cultures and more than 40% in outdoor ponds. (The rest of the plant mass is mostly protein and carbo-hydrate and could be converted to methane by bacteria or used as a boiler fuel.)

Many Favorable Factors

There are many factors that make biodiesel from microalgae an attractive marriage of low-value resources and circumstances, all present in the American Southwest, in order to fill a needed niche.

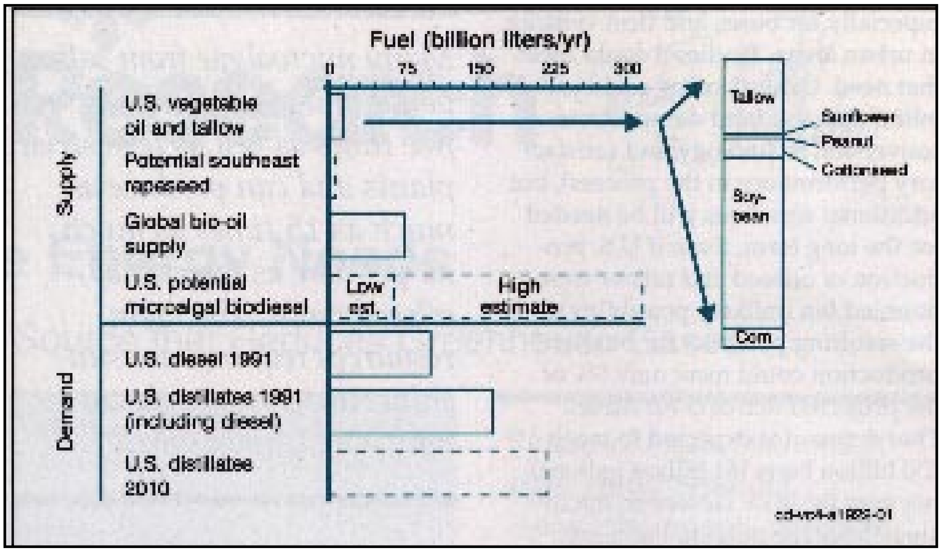
- Many microalgae thrive in water that contains as much or more salt than seawater; such water is readily available and useless for other purposes.
- Microalgae derive their energy from the sun, and many varieties can withstand high temperatures. This characteristic makes them ideal for the desert Southwest.
- As with any plant that fixes energy by photosynthesis, microalgae take up carbon dioxide (CO_2); CO_2 is a principal greenhouse gas in global climate change scenarios.
- To achieve vigorous growth rates, microalgae require much more CO_2 than can be taken directly from the air; electric power plants are faced with potential major costs to reduce their CO_2 emissions; plants making alternative fuels such as synthesis gas or biocrude oil and ethanol from biomass will also produce carbon dioxide.
- Carbon dioxide requirements represent the largest anticipated cost for producing biodiesel from microalgae—nearly one-third of the cost now and two-thirds when the technology is better developed; if power plants are required to reduce their CO_2 emissions and are paired with such biodiesel production facilities, that cost could be substantially reduced.
- Diesel fuel is generally produced as a coproduct of petroleum refining to produce gasoline. If ethanol, methanol, or other alternative automotive fuels successfully displace a significant portion of conventional gasoline production, there will be a corresponding need for an alternative to conventional diesel fuel.

Photo not available for distribution on the Internet

Lewis Brown

Microalgae can be grown in outdoor facilities such as this 0.1-hectare (1/4-acre), 15-cm (6-in) deep pond. The paddle wheel at lower right provides circulation. Carbon dioxide and other nutrients are added to optimize growth and lipid production.

NREL is using genetic engineering to better understand lipid biosynthesis and other aspects of microalgal growth. There are two primary components to this research. One is to identify, clone, and sometimes alter the genes for desired traits. The other involves transferring desired genes into an appropriate host strain. NREL scientists have isolated and cloned a gene responsible for producing an enzyme that is probably key to production of lipids. With regard to transferring genes, NREL researchers are currently working on getting the DNA containing the new gene through the cell wall of the host, and on techniques for confirming that the new genes are active in the host cell.



Biodiesel supply and demand

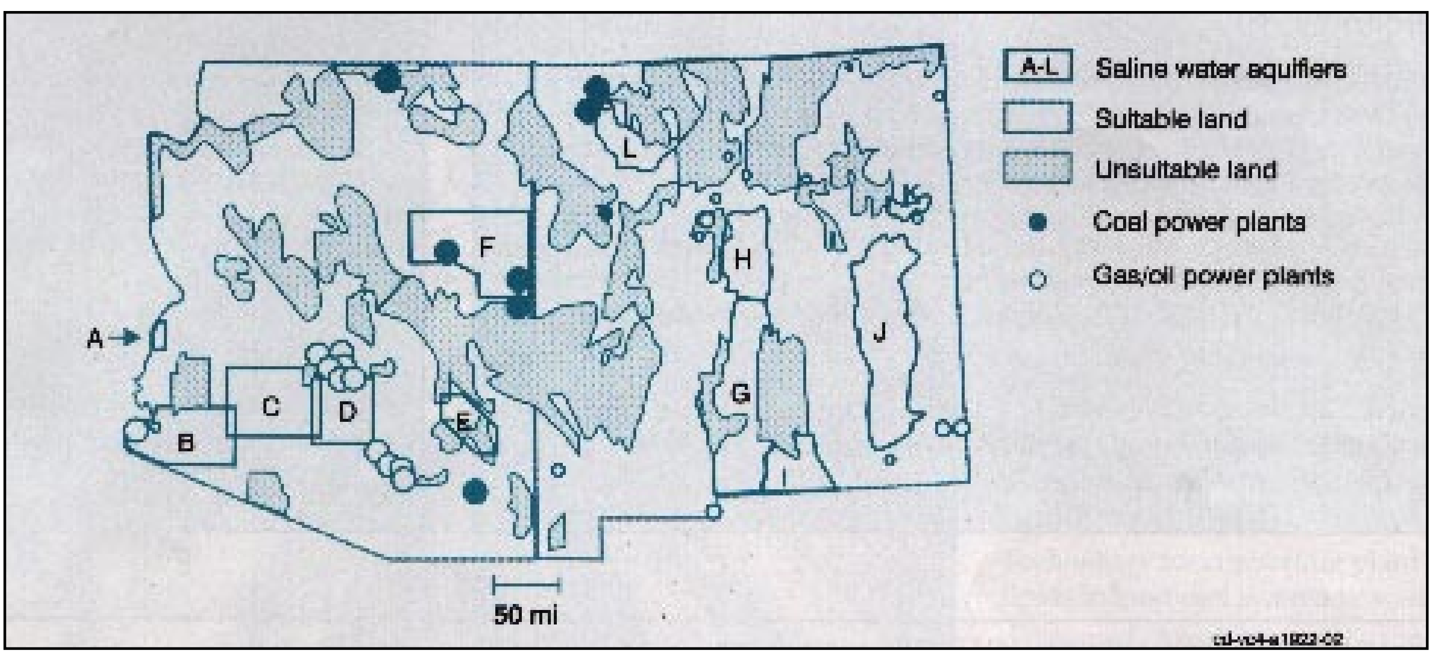
Potential Tool for Reducing Greenhouse Effect

Another major impetus for microalgal research in the last several years has been increased concern over possible global climate change resulting from CO_2 emissions to the atmosphere. NREL is examining the highly promising potential of microalgal culture as a way of recapturing CO_2. All plants require CO_2, but microalgae grow and recapture CO_2 up to five times faster per unit area than terrestrial plants.

With this in mind, NREL researchers are particularly interested in pairing microalgae ponds with flue gas exhaust from fossil fuel power plants. These power plants contribute more than one-third of U.S. CO_2 emissions and will likely be required to reduce those emissions in the near future. If so, they could provide a low-cost and concentrated source of CO_2—the biggest cost factor for producing fuel from microalgae. NREL is currently studying the impact of various flue gas components on laboratory microalgae and collaborating with electricCO_2 capture.

Microalgae Could Meet Much of the Diesel Demand

To address air quality concerns, an alternative to diesel fuel is needed,



Land, saline water resources, and power plants in Arizona and New Mexico especially for buses and fleet vehicles in urban areas. Biodiesel could meet that need. Oilseed crops could satisfy initial demand (and demonstrate conversion technology and satisfactory performance in the process), but additional resources will be needed for the long term. Even if U.S. production of oilseed and tallow were doubled (an unlikely possibility), the resulting potential for biodiesel production could meet only 5% of the projected demand for diesel. That demand is expected to reach 230 billion liters (61 billion gallons) per year by 2015. However, microalgae have the potential to meet much of that demand.

Many microalgae from saline ponds and other sources grow five times as fast as terrestrial plants and can produce as much as 15 times as much oil per acre as terrestrial oilseed crops. The main resources required are sunshine, water, some vacant land, and carbon dioxide.

At target productivity levels, microalgal biodiesel facilities using the CO_2 emissions from existing electric power plants in Arizona and New Mexico could produce 16 billion liters (4.2 billion gallons) of biodiesel per year. Those facilities would require only 0.25% of the land area of the two states, but they could produce enough microalgae to meet 14% of the present U.S. demand for diesel.

To make such a contribution economically feasible, NREL and DOE have set a goal of developing technology to produce biodiesel from microalgae at a competitive price by 2015. Microalgal lipids could also be made into substitutes for fuel oil and other petroleum distillates. In the process, microalgal lipid production may also provide a means to reduce the threat of climate change caused by CO_2 emissions.

Publications

Brown, L.M. (1993). "Biodiesel from Microalgae: Complementarity in a Fuel Development Strategy." *Proceedings: First Biomass Conference of the Americas, Vol. II.* NREL / CP-200-5768. Golden, CO: National Renewable Energy Laboratory; pp. 902-909.

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